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# EXPERIMENTAL INVESTIGATION OF QUENCHING TEMPERATURE INFLUENCE ON THE MECHANICAL PROPERTIES OF H13 STEEL

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***ABSTRACT***

***The main objective of this article in the experimentally investigation of the influence of die heat treatment on the surface hardness and wear properties of H13 steel. Heat treatment forH13 steel experiments were carried out under different quenching temperatures and the samples were tested to examine its mechanical properties, hardness, and roughness. The results of this study show that the mechanical properties of H13 was brilliant at 1020°C after vacuum quenching. The mechanical properties of H13 where measured at 1020°C and the values of hardness and tensile equal to 54.1HRC and 1994.5Mpa, respectively. The optimum roughness temperature was to found at 1080°C and the optimum roughness is equals to 0.36 $*10^{-6}$ micron.***

***KEYWORDS: Heat Treatment, Hardness, Roughness & Quenching***

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Original Article

## INTRODUCTION

Heat treatment is a technique used. Heat treatment has been employed historically, and the most well-known applications is the forging of the Japanese sword (Katana). It was adopted from the Chinese where it has been used by since the Qin Dynasty around 2500 years ago. Enhancement of mechanical properties during heat treatment of steel has been studied extensively. For instance, great enhancements have been reported on the improvement of heat treatment efficiency for H-13 steel [1].

One of the most common process that is used to change the mechanical and metallurgical properties of industrial materials. Heat treatment can be performed either by cooling or by heating. The process of steel heating to elevated temperature and converting it completely or partially to austenite is called austenitizing. The austenitizing temperature can be estimated from phase-diagram of the steel alloy.

Austenitation process involves a phase-change, which requires time and heat. In this process, steel is subjected to high temperature during particular period of time to obtain the required homogeneity of composition and to procedure the new phase to form [2].

Rapidly cooling the austenite should be carried out to avoid passing through the nose of the TTT curve. The cooling rate depends on the quenching media and the heat transfer rate in the steel work piece. Many quenching fluids are utilized in commercial heat treatment applications such as brine, fresh water, still oil; and air. The fastest cooling of the heated work piece can be achieved by agitated brine, while quenching by air is the slowest process. The main draw back in effective quenching media is it will cause internal distortion, cracks in the product and stresses [3].

Usually dies are fabricated from strong materials because they are subjected to rapidly acting and heavy loads. Dies are used many times therefore it should be capable to meet very high loads with less wear and deformation. The geometry of the required products can be varies due to die casting or hot forged damage modes, this is mainly due to wear and heat cracking. The stamping forcers are abruptly growths to a certain maximum value and then drops to the minimum. This trend is due to cold work tool steels. This results in a magnificent variable load on the punch member and die. The main required parameters for good stamping die are high wear resistance, sharp cutting edge, high hardness and significant toughness are.

The main damage modes are determined by both the process and material characteristics. Die failure are dependent on the critical hardness value that should not be exceeded for a certain application. The effect of ductility on die life is higher than the effect of toughness. Ductility and toughness are the main properties that influence the hardness. Many die manufacturers are suffering from bad selection of system parameters, during heat treatment of die components. The selection process is based on experience or trial and error techniques. When the die production process is not optimize, early failure can be take place.

The properties of a material (physical and chemical) can be modified by austenitization. Austenitization process is considering one of the most common industrial and metal working process. The austenitization can be utilized to process when heating and cooling are applied intentionally modify the properties. It includes many steps such as annealing, case hardening, precipitation hardening, quenching and tempering.

Machine-ability is the main practical and economical significance to obtain the required properties of mold steels. Most of mold manufacturing cost is because off increasing the material removal. Machine-ability of materials can got worse, machining due to hardness, hence pre-hardened condition is very critical.

For molding molten metal under high pressure are used in die-casting. Die-casting has extensive modern manufacturing applications processes. Under working condition dies suffer significant impact and cyclic heating and cooling, while contacting elevated temperature metal (500 – 700°C). To illustrate, through aluminum die-casting, molten aluminum (700°C) is added to the mold at velocities between 30 m/secto 100 m/sec, with pressures(500bar – 800 bar)[4 – 5].

Hot extrusion commonly applied for fabrication processes used to construct simple and complex profiles aluminum alloy for automobile, aerospace, and other industries. H13 steel dies are utilized for commercial aluminum extrusion like the above mention. Recent works found that wear, fracture and deflection are the most regular failure mechanisms of die are e, [6].

The heat treatment process cost can be neglected comparing with the total fabrication cost, but it is the most significant step on obtaining the quality of material. The influence of the surrounding conditions during heat treatment process one the material hardness profile is studied extensively. In addition, many studied were aimed to investigate the effect of carbon content in the material on tempering response and performance of the nitriding. Heat treatment to H13 steel samples with specific sizes were examined using different duration time and atmospheric conditions. After that, the hardness profiles of each sample were measured. The influence of the gas nitriding process effectiveness on heat treatment with and without atmospheric control is also investigated. Hardness profile is measured while the work piece would additional be exposed to nitriding case hardening process.

H13 steel is widely used as die-casting mold, die forging and hot-extrusion. It has several merits such as high harden-ability, toughness and abrasive resistance. Carbide is important as a second phase in H13 steel. The size, morphology and distribution of carbide are important factors affect the performance of steels. Researches interpreted the effect of carbides in H13 die steel.

Two to three cycles of high temperature tempering process is usually required, and the practical tempering temperature is 450°C - 520°C for H13 steel. In industrial practice, the extrusion dies are tempered twice: 1st tempering is at 540°C; and 2$^{nd}$ at 595°C, each stage required two hours. With the 1st tempering temperature, 2nd hardening may initiate within a temperature range of 400°C and 550°C, because special carbides will be expelled from Martensite [7-8].

Material deterioration (which is a loss in materials directly or indirectly) is the most important cause of financial losses in industrial The direct loss in materials leads to damage parts that depends on the direct damaged part which produces the indirect loss. Over dimension of structures and equipments, the losses imposed to the society and the environment impact due to toxic or inflammable chemical accidents or leaks are the main adverse effect of material deterioration. Deteriorated materials quantity varies from 15 to 25% of the steel produced in the world, which is equivalent to 4.0% of the gross product industrially produced. [9]

Based on literature review, the annealing temperature and holding time is the main parameters of the hardness of the material. In addition, it can be clearly found that spheroidal annealing process caused increasing in the corrosion resistance of the material. In previous study, they found the best time for hardness and corrosion resistance annealing spheroidal at 740°C are 60 min and 45 min respectively [10].

Indentation is well-defined as resistance of metal to plastic deformation. In addition, this term can be referred to stiffness, resistance to scratching, temper, abrasion, and cutting. This property is a measure of material the ability to resist permanent deformation, deformed (bent, broken, or shape alert), when a load is applied. As the hardness of the metal increases this resistance is increased. The material resistance to scratched by another material is called mineralogy. In metallurgy, the ability of a material to resist plastic deformation is called hardness,.

Indentation hardness according to the dictionary of metallurgy is defined the as the resistance of a material to indentation. This proprieties can be measured by usual type of hardness test, in which a rounded indenter is pressed into a surface under a considerably static load.

Martensite is created when critical temperature iron–carbon steel alloys are quickly cooled (or quenched) to a comparatively low temperature. Martensite phase is unbalanced mono structure undergoing transformation austenite. It may be reflection of as a transformation product that is bainite and pearlite. Transformation occurs martensite when the cooling rate is fast enough to prevent the prevalence of carbon. Any spread at all would lead to the formation of ferrite and cement. [11]

In order to enable the mold to work with long term stability the in-service tool must have high strength, hardness and a certain degree of impact toughness. [12]

Aluminum alloy profiles (automobile, aerospace, and other industries) can be produced using hot extrusion. H13 steel dies are mainly utilized to fabricate commercial aluminum. Recent research works reported that the most frequent of die failure causes are fracture, wear, and deflection. Dies are subjected to temperature cyclic loads during commercial aluminum extrusion process. Along with high extrusion pressures, this can result in critical failure due to fatigue fracture or extreme plastic deformation.

Consequently, high friction at the die-billet produces an excessive wear. In order to get a best combination of high hardness and toughness, dies should be heat-treated and surface hardened carefully. Precise profile geometry and prolong life of the die is a crucial issue. The understanding of properties to these materials, and their variation using different heat treatments and operating temperatures, is thus significant. [13]

One of the most significant manufacturing process that is used to enhance the mechanical properties is heat treatment. This alteration has important effect on the performance of the die material. Gas carburization, pack carburization, induction heat treatment, salt bath, and vacuum heat treatment are examples of different techniques of treatment hardening. The main steps of heat treatment consists: preheat cycle, austenite formation, quenching and tempering. These process lead to harden the material while the austenite structure is changed to martensite structure,. [14]

## EXPERIMENTAL PROCEDURES

Experiments were designed to investigate the effect of quenching temperature on the mechanical properties of H13: hardness, roughness and tensile experiments on H-13 steel.

The following table illustrates the chemical composition of H13 tool steels.

**Table 1: Chemical Composition of the Specimens**

| Element | Content (%) |
|---|---|
| Cr | 4.75 |
| Mo | 1.10 |
| Si | 0.80 |
| V | 0.80 |
| C | 0.32 |
| Ni | 0.3 |
| Cu | 0.25 |
| Mn | 0.20 |
| P | 0.03 |
| S | 0.03 |

Appropriate heat treating needs precise control of overheating, cooling rate, and time-held at a certain temperature [15]. It can be found that most heat treatments begin by heating an alloy beyond the upper temperature of transformation (A3) for tempering, stress-relieving, and aging. This result, it was as expected because the upper temperature is referred to as an "arrest". Therefore, the metal involvements a period of hysteresis. This situation causes crystal change thus all required energy is consumed, therefore the temperature at this period remains constant for a while after that, it will be increasing when completing the change [16]. In order to produce a Martensite transformation, the rapid rate of a metal cooling process is done (quenching).

The hardening process was performed as follows:

- Pre-heating temperature at 650℃.
- Heating the specimens at 960℃, 990℃, 1020℃, 1050℃ and 1080℃.
- Holding time for 20min.
- Quenching in oil.

Figure 1 illustrates the aforementioned steps involved in hardening.

A specific temperature is applied to tempering consist of quenching. This temperature is must be higher than Martensite start temperature. If the temperature will be kept at that level, pure Bainite can be formed or internal stresses are relieved. These include Austempering and Martempering [17].

The tempering process was performed as follows:

- Heating at 550℃
- Holding time for 2hr
- Cooling in furnace

Figure 2 illustrates the aforementioned steps involved in the tempering process.

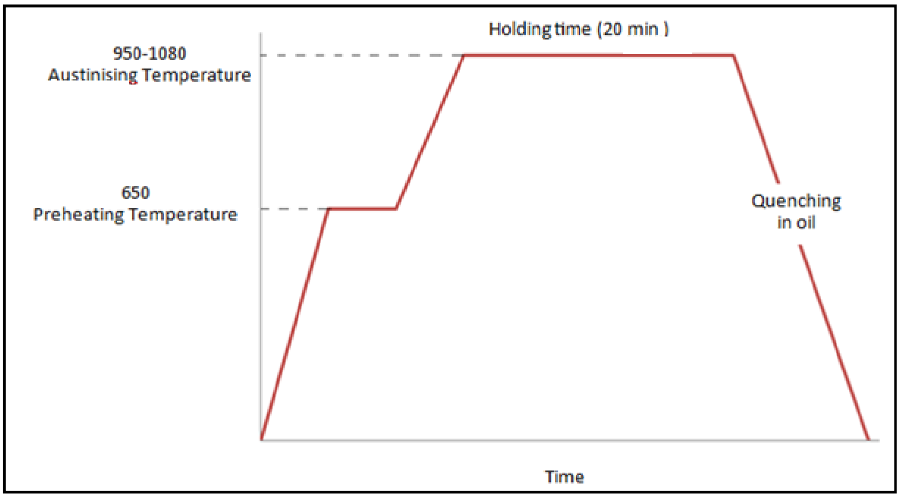


**Figure 1: Temperature Profile used in the Hardening Process.**

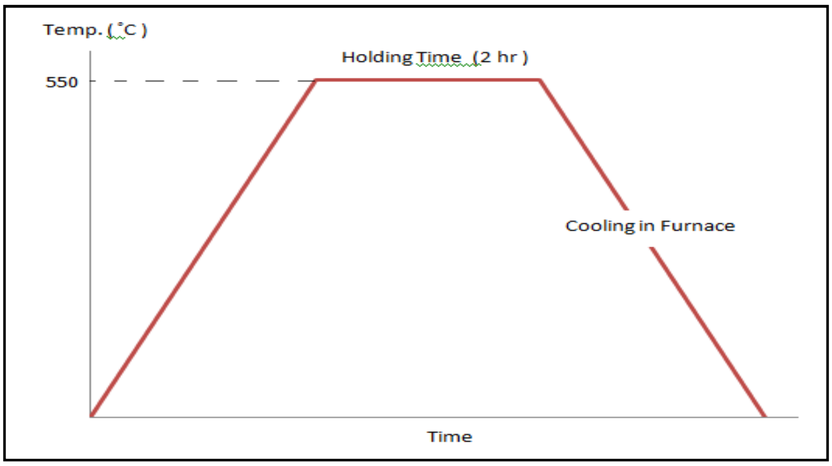


**Figure 2: Temperature Profile used in the Tempering Process.**

Finally, experiments were performed on H-13 steel to study the effect of quenching temperatures at 960°C,990°C,1020°C,1050°C,1080°C on the standard values of tensile strength, hardness and roughness.

**Hardness**

Table 2 below shows Rockwell Hardness values of steel H13. Original hardness was 17.2 HRC (210 HV).

**Table 2: Rockwell Hardness values of steel H13**

| Heat Treatment Temperature (˚C) | Hardness (HRC) | | | |
|---|---|---|---|---|
| | HRC | HV | HV (Ref.18 ) | % error |
| 960 | 33.5 | 311 | 400 | 28.6 |
| 990 | 44.7 | 438 | 500 | 14.2 |
| 1020 | 54.1 | 589 | 540 | 8.3 |
| 1050 | 45.6 | 448 | 580 | 29.5 |
| 1080 | 42.6 | 406 | 590 | 45.3 |

The results presented in this work were validated by comparing with the reported results of Ref. (18). The maximum relative error was 45.3 % and the minimum error was found to be 8.3. The average error was calculated as 25.2 % which is acceptable. The deviation of the present results compared to Ref. (18) can be attributed to the difference in the alloy composition specially in C% and Cr%.

**Roughness**

Table 3 below shows Roughness values of steel H13. Original roughness was 1.16 Micron.

**Table 3: Roughness Values of Steel H13**

| Heat Treatment Temperature(˚C) | Roughness (Micron) | | |
|---|---|---|---|
| | Point 1 | Point 2 | Average |
| 960 | 0.675 | 0.575 | 0.625 |
| 990 | 0.52 | 0.49 | 0.515 |
| 1020 | 0.45 | 0.45 | 0.45 |
| 1050 | 0.42 | 0.39 | 0.385 |
| 1080 | 0.37 | 0.35 | 0.36 |

**Tensile Results**

Table 4 below shows tensile strength values of steel H13. The original ultimate tensile strength value is 1395 MPa.

**Table 4: Show Tensile Strength Values of Steel H13**

| Temperature ($^{o}$C ) | Ultimate Strength (MPa) | Ultimate Strength (MPa) (Ref. (18) | % error | Tension Force (KN) |
|---|---|---|---|---|
| 960 | 1559.7 | 1600 | 2.6 | 44.1 |
| 990 | 1750.7 | 1710 | 2.2 | 49.5 |
| 1020 | 1994.5 | 1759 | 11.8 | 56.4 |
| 1050 | 1814.4 | 1910 | 5.3 | 51.3 |
| 1080 | 1535 | 1655 | 7.8 | 43.4 |

By comparing with the reported results in Ref. (18). The maximum relative error was 11.8 % and the minimum error was found to be 2.2. The average error was calculated as 5.94 % which is acceptable. The error in the UTS is much less than the error in the hardness values.

## CONCLUSIONS

The following conclusion can be summarized based on the this experimental study

- On H13 tool steel the hardness there is normal distribution curve by the austenite temperature 960, 990, 1020, 1050 and 1080, the best result was at 1020℃.
- H 13 tool steels should be hardened in a controlled protective atmosphere furnace followed by oil cooling to

achieve high hardness possible.

- Tempering is needed to impart ductility to Martensitic with a small sacrifice in strength.
- Roughness decreased with increases in Austenite temperature.

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